ARTICLE X.

On Irradiation. By Benjamin F. Joslin, M.D., Professor of Mathematics and Natural Philosophy in Union College, Schenectady, New York. Communicated by Dr Isaac Hays. Read July 15, 1831.

ASTRONOMERS generally admit the existence of a species of dilatation of the apparent magnitudes of luminous bodies, which is called *irradiation*, the amount of which has not been exactly measured, nor the cause explained on any physical or physiological principle; and as it produces an augmentation of the apparent diameter of the sun's disc, they are compelled to make an approximate allowance for it in the calculation of eclipses, whose time of beginning and duration, as calculated from the measured apparent diameters of the sun and moon, it is thought sensibly to affect.* I am not aware that this amplification has been suspected to be greater in one direction than another. This may be one reason why its influence on particular phenomena has not been more accurately ascertained, and why its assumed value has been justly considered so unsatisfactory an element in astronomical calculations.

I shall state some of the laws of this phenomenon, which I think I have established, and particularly the determinate directions in which the maximum irradiation generally takes place in the human eye. I shall also propose an hypothesis respecting the cause of this phenomenon, or at least its connexion with a certain anatomical structure.

I know not whether there is any plausible hypothesis respecting the

* It does not however affect the *actual* time.

cause of irradiation. The subject is rarely mentioned in books, and still more rarely is there found any thing but a bare mention of the fact. M. Biot, in his valuable work on physical astronomy, avoiding, as usual, every expression which might involve any hypothesis not apparently warranted by known facts, has the following incidental notice of this subject, with reference to the phases of Venus. "Ces diminutions et ces accroissemens ne sont pas sensibles à la vue simple, à cause de l'irradiation qui dilate un peu les diamètres apparens des objets, et d'autant plus qu'ils sont plus éclairés." This expresses the fact of the dilatation, and its increase as the objects are more luminous. This is probably the only law of the phenomenon hitherto known. I have searched several works on physiology, optics and astronomy without finding any thing written expressly on this subject, except a single page in Delambre's complete work on theoretical and practical astronomy, from which the following extracts have been made. "On a supposé que les diamètres des objets lumineux étaient amplifiés par l'*impression vive* que leur lumiere produit sur l'organe de la vue ***** qu'il faut dépouiller le sòleil de cette couronne lumineuse qui l'entoure, non pas en réalité, mais dans notre œil ***** c'est un point qui n'est pas encore suffisamment eclairci."

From the last of these extracts (referring apparently to the existence, precise amount and cause of this amplification), we learn that it requires further investigation; from the second, that it is believed to exist only in the eye; and in the first, there seems to be an intimation that it depends upon the sentient part of this organ. It, therefore, appears to be an interesting and legitimate object of physiological inquiry.

I am far from professing to be able at present to supply all the desiderata on this important subject, yet I cannot but hope that I may have facilitated the attainment of this object, by the discovery of some new laws of irradiation, and perhaps the anatomical structure, if not the optical principle on which it depends.

One new law, which I think established by induction from numerous facts, may be enunciated as follows. There are determinate directions of maximum irradiation for every individual: these in man, for ordinary vision, are generally three in number, and are at equal angular distances, which are consequently one hundred and twenty

degrees, or one third of the circumference of the circle; one direction being, in the erect position of the head, directly upward in a vertical visual plane passing through the centre of the luminous object, the two other directions obliquely downward, in visual planes which respectively make angles with the former and with each other of one hundred and twenty degrees.

Every one has observed a radiated appearance of the stars, and of the flame of a distant lamp or candle. In examining these objects attentively, I discovered that three of these rays were far more conspicuous than the others, and were equidistant from each other, and that one of them was directed vertically upward. Among the heavenly bodies this was more conspicuous in the larger and brighter planets, and in the fixed stars of the first magnitude.*

By repeating similar observations on luminous objects at less distances, as the flames of lamps and candles at distances varying from a few feet to several hundred, it was found that the dilatations in those determinate directions were by no means confined to the narrow, faint and elongated radiations which constitute the more obvious features of the stellar appearance, but that the body of the flame itself assumed a distinctly triangular figure, in consequence of a dilatation in precisely the same three directions.

In order to divest the results of any influence produced by the actual figure of the flame, as well as to determine the effect of different magnitudes, a circular metallic plate was mounted on an horizontal axis with liberty of motion in a vertical plane at right angles to the visual ray, and pierced with unequal circular holes disposed in a circle concentric with the axis; by the occasional rotation of the plate these were successively brought between the eye and the flame, very near the latter; and their successive projections upon it afforded luminous objects perfectly circular. Different wires, meeting at the centre of the aperture, and stretched in a plane parallel to and near the disk, and furnished with movable beads, afforded a simple instrument for determining the direction and extent of the irradiation; though the

* To the well known radiated appearance, especially that of the sun, the Latin writers applied the term coma. Hence, *sol auricomus*, the sun with golden radiations.

determination of the latter has not as yet been attempted with much precision, but was found, as might be expected, to increase with the intensity of the light.

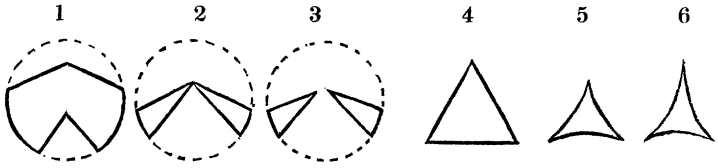
With this apparatus the preceding results were verified, and others obtained. At a distance of from five to fifty feet, the luminous object, actually circular, presented the appearance of an equilateral triangle, whose outlines were pretty well defined, especially when the metallic disk was illuminated on the side next the eye by another candle, in order to render the retina insensible to the extremities of the narrow and especially the irregular radiations. At greater distances, the aperture being of the same magnitude, the narrow radiations became more conspicuous, the regular ones always predominating. An increase in the magnitude of the object increases the distance requisite to produce the distinct triangular appearance. With an object one-tenth of an inch in diameter, it is most distinctly seen at the distance of six or eight feet; with one of one-fifth of an inch, at twelve or fifteen feet. It is also seen pretty distinctly at double these distances respectively, and with large objects at a great and probably indefinite number of miles, provided their angular magnitude is sufficiently great to prevent the preponderance of the narrow rays, and yet not so great as to render this change in form imperceptible. With an object whose light is originally faint, or rendered so by traversing a great extent of atmosphere, the effect is less, and may become insensible.

The foregoing experiments were varied and the principal results verified, by viewing opaque objects surrounded by luminous ones, instead of luminous ones surrounded by an opaque one as before. A single example may suffice. A circular opaque disk, projected on the flame of a candle, but extending beyond it laterally, appeared deprived of two superior oblique segments, by downward and oblique dilatations of the superior part of the flame in the same directions as in the former experiments; also of a kind of sector at the inferior part, by the upward vertical dilatation of the inferior part of the flame. In consequence of the encroachment of the flame upon the disk in these three directions, as the observer receded from it the disk was reduced in magnitude and changed in form, and finally, by the encroachment of the inferior portion of the flame by upward irradiation, was divided into

two lateral portions. This was in exact accordance with preceding results.

The experiments hitherto related have, at my request, been since repeated by others, and their verification, in almost every instance, establishes the following general law. *There are determinate directions of maximum irradiation for every individual: these in man, for ordinary vision, are generally three in number, and are at equal angular distances, and consequently one hundred and twenty degrees or one-third of the circumference of the circle; one direction being, in the erect position of the head, directly upward in a vertical visual plane passing through the centre of the luminous object, the other two directions obliquely downward, in visual planes which respectively make angles with the former and with each other of one hundred and twenty degrees: the decrements of dilatation in other directions are nearly symmetrical and equal with respect to these three directions, and the apparent form of the object approximates more or less to that of an equilateral triangle, according to its brightness, distance and magnitude.*

Figures 1, 2 and 3 represent the apparent forms of an opaque circular body projected upon a luminous one; and 4, 5 and 6, those of a luminous circular body projected upon or surrounded by a dark one.



In these last, as well as in the former experiments, the dilatation increased with the distance; it also increased with the intensity of the light. In fact, on this last account, a straight horizontal rod, by the apparent curvature of its lower edge when projected on the flame of a candle, becomes a tolerably delicate photoscope, for detecting the less degree of illumination of the interior of the flame at heights above the base where the difference between the interior and exterior brightness is inappreciable by direct and simple observation.

During the experiments with the circular luminous objects, when the head of the observer was inclined to the right or left any number of degrees, the vertices of the luminous triangle, as also the long radia-

tions, were found to undergo a change of absolute position exactly correspondent in direction and extent with that of the head, whilst their relative position remained invariable. This proved that the phenomenon depended on no cause exterior to the human body. When an opaque substance was interposed between either eye separately and the object, the triangular appearance was preserved, but the inferior vertex was more obtuse and the oblique radiation shorter on the side of the eye whose vision was obstructed. This proved that the effect depended in part, but not chiefly, upon the combined action of the two organs. Moreover, as the appearance was unaffected by the careful removal of the ciliae and eyelids from before the cornea, and as I had long since examined the separate effect of the tears, it appeared evident that irradiation depended upon none of the tutamina oculi, but was to be referred either to the refracting or sentient parts of the proper organ of vision.

Several considerations seemed to me to exclude the latter. If a vivid impression on any spot of the retina could produce a similar affection of adjacent parts, there is no obvious reason why this sympathetic affection should be more widely diffused in certain determinate directions which sustain no possible constant relation to the distribution of its fibres or to its structure in any respect; directions which are constant both in the case of oblique and of direct vision, and on whatever part of the retina the image may be situated, with respect either to the optic nerve or the centre of its medullary and membranous expansion. The views which were suggested by considerations of this nature, were confirmed by subsequent experiments; experiments which proved the phenomenon under consideration to be independent of any peculiarity in the sensation, and the retina to have no share in its production, in any other sense than as it is essential to vision in general.

When most of the preceding experiments had been made, I, for the first time, thought of the striking coincidence between this dilatation of luminous bodies in three equidistant directions, and the three equidistant sets of fibres and three equidistant radiated lines, exhibited in the front view of the crystalline lens of the ox, as represented by that eminent philosopher, the late lamented Thomas Young, M.D., in his

"Observations on Vision."* He afterwards learned that these three sets had been previously seen, though less accurately observed, by Leeuwenhoek. Dr Young describes each coat as consisting "of six series of fibres, intermixed with a gelatinous substance, and attached to six lines which have somewhat of a membranous appearance. Three of these lines or tendons are anterior, three posterior; their arrangement is that of *three equal and equidistant rays meeting in the axis of the crystalline.*" He adds, "I have not yet had an opportunity of examining the *human crystalline*, but from its *readily dividing into three parts*, we may infer that it is similar to that of the ox." Here I conceived I had found a clue to the cause of the phenomenon, in a structure which seemed calculated to produce an action symmetrical with respect to three equidistant radii of the crystalline lens; a structure to which there appears to be nothing analogous in any other part of the organ of vision. The deviations from this arrangement of the fibres, which may have been detected by Dr Young and others, will not be at present considered,† and will not probably affect the proof of a connection between irradiation and the structure of the crystalline, so long as there exists the *more obvious division of this body into three similar sphenoidal portions.*

In the prosecution of these researches on the subject of irradiation, I have made several other experiments, especially with the pupil preternaturally dilated. These will not be at present detailed, but reserved for a future communication. I shall, however, venture to state some of the inferences which they appear to justify, which are the following.

1. That irradiation is produced directly and chiefly by the crystalline lens, but affected by the iris. 2. That the different fasciculi of the fibres of the crystalline exert, in some respects, a similar though

* Young's Natural Philosophy, Vol. II. p. 525.

† The greater number of fasciculi which Dr Young subsequently detected, and their occasional diversity and irregularity may perhaps explain the existence of intermediate radiations in all eyes, and the absence of one of the more conspicuous and regular ones in some rare instances. But I shall not venture to attempt an exact account of the optical and anatomical structure of the lens, cornea and iris, and their correspondence with the other laws of irradiation which I may have discovered, until I shall have had access to the papers of Dr Brewster and Sir E. Home on the former subjects, only a brief notice of which has been inserted in the scientific journals.

unequal action on light. 3. That the central and lateral parts of this body conspire in different degrees to produce irradiation; the effect increasing with the absolute distance of the incident ray from the axis of the crystalline, and consequently with the magnitude of the pupil. 4. That there are two distinct species of irradiation, in consequence of which the unequal luminous border superadded to the perfect image on the retina, by this kind of aberration, is composed of two distinct though partially superimposed parts, of different colours, the superimposed portions of which on any one point of the retina, are produced by the action of opposite wedges of the crystalline.

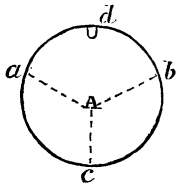
A popular *application* of the foregoing results is, that *we never see luminous objects of their true shape.* Of the existence of this species of optical illusion, any person may readily convince himself, by examining the flame of a candle when near it, and then withdrawing to the distance of thirty or forty feet, or even across an ordinary room. How frequently must we have been deceived in our estimate of form as well as magnitude! It is unnecessary to dwell on the importance of being apprized of an illusion, which affects in no small degree the testimony of one of our most interesting and valuable organs of sense.

We learn also from the results which I have obtained, that the appearance of luminous objects, with respect to position, shape, and occasionally colour, is materially affected by their brightness and distance, and by the *position of the head*, and the *magnitude of the pupil or other aperture* through which the rays are admitted into the eye; and that these effects are constant for the same individual, in the natural state of the eye, and, with few exceptions, essentially the same for all.

On these principles we may probably explain the *apparent projection of a star upon the moon's disk* at the time of an occultation, a phenomenon which has occasionally astonished the ordinary and accidental observer, and been "at all times an interesting and important subject to the astronomer,"* to whom it has been perhaps scarcely less inexplicable. It appears to me that irradiation affords a solution, and that the laws I have detected may enable us to explain and even to predict the apparent anomalies: viz. its being more frequent in the

* American Almanac for 1831, p. 34.

case of particular stars, its not always existing in the occultations of the same star, nor being seen by all individuals. If this theory be correct, the existence of this phenomenon, and the distance to which the star is thrown upon the moon's disk, depend upon the position of the head of the observer, and the relative direction of the moon and star at the time of immersion or emersion. The more frequent appearance of this phenomenon in the case of the brighter stars, and on the luminous side of the disk, seems to depend upon the greater dilatation of the more luminous bodies, whilst the duration will depend upon the magnitude of the star, and the direction of the moon's motion. The effect of position will be understood from the following experiment in connection with the foregoing statements. A circular opaque disk, A, was placed between the eye and a luminous circle, of which a part projected beyond the edge of the disk. At *a*, *b* and *c*, the stellar or radiated appearance was most conspicuous on the disk, whilst at *d*, near the superior part, it appeared more like a real luminous body on the disk, of a *reddish* colour, and well defined, and almost or entirely projected on it. By inclining the head, the places where these phenomena were most perfectly exhibited, suffered a corresponding change, their relative position remaining invariable. The appearance at *a*, *b* and *c* is in accordance with what has been herein stated with respect to the three directions of maximum irradiation; that at *d* will be explained by experiments which I had previously made on the human eye, and which will be hereafter published with a generalization of the facts.



Among the *other astronomical applications* of the laws of irradiation, the following may be mentioned. During a partial solar eclipse, a faint light is sometimes seen to be thrown on the moon near the horns of the sun, and to be brighter and longer on one side than on the other.* Moreover, I have observed one of the horns of the new moon (though apparently not more luminous than the other) to project farther than the other from the dark portion of the disk, according as they were situated with respect to the directions of maximum irradiation.

* Edinburgh Philosophical Journal, Vol. III. p. 393.

The fixed stars appear larger when viewed with the unassisted eye than when we employ a good achromatic* telescope. For a similar reason, the planet Venus, being, from its vicinity to the sun, strongly illuminated, may appear larger than Jupiter to the eye, whilst Jupiter appears larger than Venus with a telescope of such an aperture and magnifying power as to diminish the brightness and consequently the irradiation. If the construction is such as to admit but a small pencil into the eye, another cause will be found to conspire, which is the *less* amount of *irradiation* (and probably the different laws of it), for the light which is transmitted *near the axis* of the crystalline lens. This follows from the experiments already alluded to on the influence of aperture.

I shall not, however, at present, anticipate any other results of those experiments on the influence of aperture on irradiation, except to suggest the possibility of applying them to the explanation of the *twinkling of the stars;* a phenomenon hitherto entirely referred to causes purely physical, but the true cause of which is admitted to be "not fully ascertained."†

As the fixed stars are highly brilliant bodies, subtending an exceedingly minute angle, their apparent magnitudes depend almost entirely upon irradiation; and it is hence easy to conceive that any alternate and transient changes in this affection may occasion oscillations in their images on the retina. Is it not therefore possible, that this phenomenon may be affected if not produced by transient remissions of irradiation? If irradiation shall be shown to depend directly or indirectly on the crystalline and iris, it is possible that oscillatory motions in either might produce such remissions. With respect to the existence of such motions, Dr Wollaston has shown that muscular effort, when apparently continuous, consists, in reality, of a great number of contractions repeated at extremely short intervals. It may be added, that there are alternations of contraction and dilatation of the iris, which are of sensible duration and extent, and visible by direct observation.

* Or rather aplanatic, free from both species of aberration.

† Young's Natural Philosophy, Vol. I. p. 490.

Schenectady, March 4, 1831.